Aerosol climatology using a tunable spectral variability cloud screening of AERONET data

Submitted to GRL Dec 13 2005GL025478

Yoram J. Kaufman[1], Gian Paolo Gobbi[2], Ilan Koren[3]

1. NASA/Goddard Space Flight Center, 613.2, Greenbelt MD 20771 USA, (yoram.j.kaufman@nasa.gov)
2. Inst. Scienze dell'Atmosfera e del Clima, CNR, Via Fosso del Cavaliere, 100, 00133 Rome – Italy
3. Dep. of Environ. Sciences Weizmann Institute, Rehovot 76100, Israel

Abstract

Can cloud screening of an aerosol data set, affect the aerosol optical thickness (AOT) climatology? Aerosols, humidity and clouds are correlated. Therefore, rigorous cloud screening can systematically bias towards less cloudy conditions, underestimating the average AOT. Here, using AERONET data we show that systematic rejection of variable atmospheric optical conditions can generate such bias in the average AOT. Therefore we recommend (1) to introduce more powerful spectral variability cloud screening and (2) to change the philosophy behind present aerosol climatologies: Instead of systematically rejecting all cloud contaminations, we suggest to intentionally allow the presence of cloud contamination, estimate the statistical impact of the contamination and correct for it. The analysis, applied to 10 AERONET stations with ~ 4 years of data, shows almost no change for Rome (Italy), but up to a change in AOT of 0.12 in Beijing (PRC). Similar technique may be explored for satellite analysis, e.g. MODIS.

Introduction

Evaluation of chemical transport models and initiation of climate models is based on average aerosol properties measured from ground based or satellite platforms, over a given time and space interval (Chin et al., 2002, Menon et al., 2002). AERONET (http://aeronet.gsfc.nasa.gov/) cloud screening is based on variability of the 1 minute interval triplet measurements and ~15 minute interval measurements (Smirnov et al., 2000). The basic assumption is that clouds vary more than aerosols and a given threshold of variability can separate clouds from aerosol. A similar technique is used for MODIS, though the MODIS algorithm, by using two-dimensional spatial variability method is more powerful (Martins et al., 2002). Kaufman et al. (2005a) used a new spectral variability cloud-screening algorithm (SVA) of AERONET optical thickness data (Holben et al., 1998; 2001). Application to one month of data collected in Lille, France indicates that the present L1.5 AERONET cloud screening may not retain variable aerosol and reject it as clouds. Aerosols can vary due to variability in humidity, the presence of near by sources or cloud processing. Due to the correlation between the aerosols and cloud cover (Chou et al., 2002; Sekiguchi et al 2003; Kaufman et al., 2005b; Koren et al., 2005), time averaged values may be influenced by the particular use of cloud screening.

Spectral variability cloud screening algorithm

The SVA (Kaufman et al., 2005a) can represent better the aerosol climatology in case of aerosol with spectrally varying optical thickness. The physical principle behind the SVA is shown in Fig. 1. Quick observation shows that the main difference between the clouds and the aerosol in the MODIS image is the difference in color. We can also see that while the clouds are more variable than the aerosol, the heavy pollution aerosol is also highly variable. Elimination of the variable aerosol means elimination of the most concentrated aerosol. The SVA is designed to screen as clouds only measurements with significant spectrally neutral variability. Plot of the AERONET data using the SVA and L1.5 cloud screenings (Fig. 1) shows under representation of the hazy conditions in the L1.5 data. There is no indication in the time dependence of the Ångström exponent to indicate that some of the points are cloud contaminated.

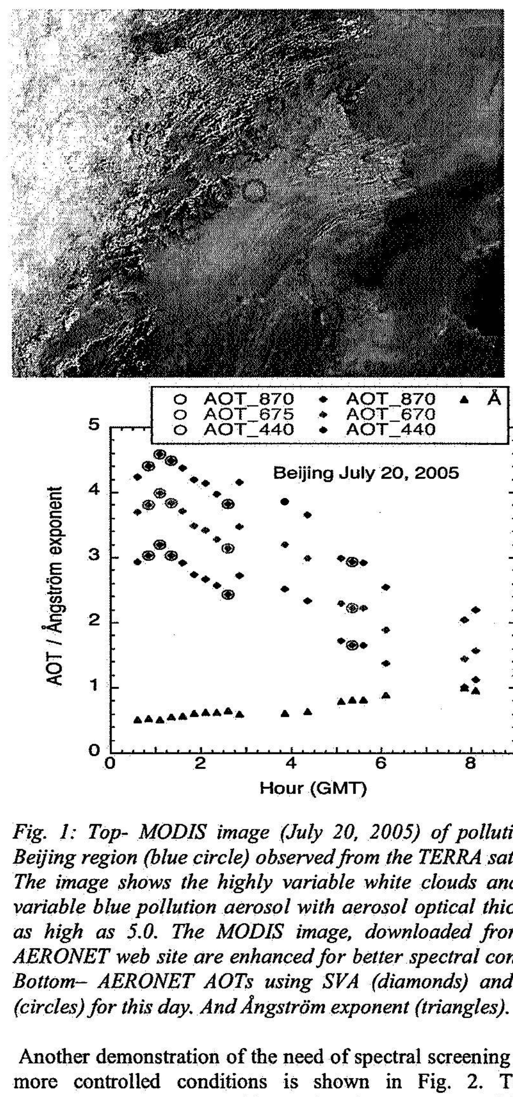

Fig. 1: Top- MODIS image (July 20, 2005) of pollution in Beijing region (blue circle) observed from the TERRA satellite. The image shows the highly variable white clouds and still variable blue pollution aerosol with aerosol optical thickness as high as 5.0. The MODIS image, downloaded from the AERONET web site are enhanced for better spectral contrast. Bottom– AERONET AOTs using SVA (diamonds) and L1.5 (circles) for this day. And Ångström exponent (triangles).

Another demonstration of the need of spectral screening in more controlled conditions is shown in Fig. 2. The measurements represent thin smoke plumes generated by numerous small fires in the Lag-Ba-Omer holiday in Israel. The spectrally sensitive SVA detects most of the smoke plumes while AERONET L1.5 rejected 2/3 of them as clouds. We can see in the figure that the rejected data, though variable, have much stronger variability in the blue spectral range than in the NIR, resulting in similar Ångstrøm exponent and indicating variable aerosol rather than clouds. Similar rejection of smoke plumes was found by O'Neill, et al. [2003].

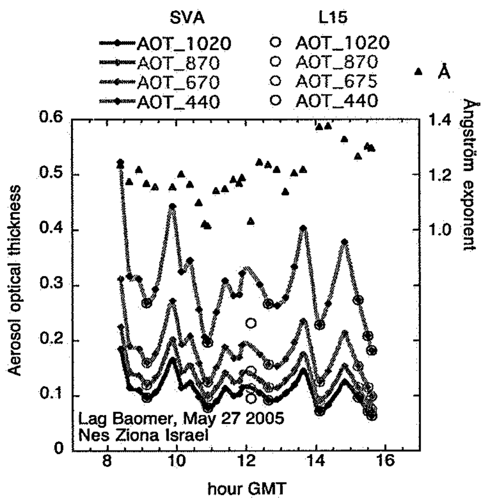

Fig. 2: Time variability of the spectral optical thickness and Ångström exponent (triangles) in Nes Ziona, Israel during the holiday of Lag-Baomer when fires are set and result in numerous thin smoke plumes. SVA (filled squares) detected most of the measurements as cloud free while less than 1/3 were detected as cloud free by AERONET L1.5. The L1.5 average AOT is about 25% smaller.

The SVA used in Figs 1-2 is applied to the level 1.0 AERONET data (that already have some preliminary high frequency variability screening) using the following criteria (after Kaufman et al., 2005a):

Triplet screening (variation over seconds) using spectral neutral variability:

$$\text{It is a cloud if: } \delta\tau^{cloud} > 0.005+0.02\tau^{675} \quad \text{With} \quad \delta\tau^{cloud} = \delta\tau^{870} - \delta\tau^{440}(\tau^{870}/\tau^{440}) \tag{1}$$

where $\delta\tau^{\lambda}$ is the spectral triplet value for wavelength λ, τ^{λ} is the measured optical thickness and $\delta\tau^{cloud}$ is the estimated variability of the cloud optical thickness. The threshold dependence on the AOT in eq. 1 represents the effect of humidity on the spectral dependence of the AOT. The cloud variability $\delta\tau^{cloud}$ (eq. 1) is the spectrally neutral component of the triplet variability. Lets take an example of aerosol with Å=1, and with the triplet variability originating only from thin cloud that is present only part of the time. Then $\tau^{870}\sim 0.5\tau^{440}$ and $\delta\tau^{870}\sim\delta\tau^{440}$. Calculating $\delta\tau^{cloud}$ we get half of the actual cloud optical thickness in this case. In another example, of pure aerosol with Å=1 but variable in time, we shall get $\tau^{870}\sim 0.5\tau^{440}$ and $\delta\tau^{870}\sim 0.5\delta\tau^{440}$ resulting in $\delta\tau^{cloud}=0$.

Adjacent screening (variation over minutes):

$$\text{It is a cloud if: } \Delta\tau^{cloud} > 0.0075+0.03\tau^{675} \quad \text{with} \quad \Delta\tau^{cloud} = \Delta\tau^{870}-\Delta\tau^{440}(\tau^{870}/\tau^{440}) \tag{2}$$

where $\Delta\tau^{\lambda}$ is the maximum difference between the current AOT and the next or previous one. $\Delta\tau^{cloud}$ is the estimated variability of the cloud optical thickness. Only data with Ångström exponent, **Å(440-870) > 0.3** are analyzed here (Å<0.3 represents clouds or pure dust conditions). If the screened value is found later to be surrounded by values declared as cloud contaminated then the value is eliminated. To be consistent with L1.5 data we screen out measurements for solar zenith angle > 78.5°.

Application of the SVA algorithm is shown for 4 locations in Fig. 3 and compared with the AERONET L1.5 algorithm. The SVA generates larger AOTs in Beijing and ISPRA for Å<1. These were found to be the heavy pollution conditions indicated in Fig. 1. The density of measurements increases all along the Å axis, and is most pronounced in Beijing for Å~1.3 and in Alta Floresta in the presence of biomass burning smoke for Å~2.0.

Aerosol climatology

The density of measurements, the average AOT, and Å depend on the threshold of the SVA (Fig. 3). Thus even though SVA allows variable aerosol to be considered as aerosol rather than clouds, in the presence of cloud contamination the variable aerosol is still screened out with the clouds. Is there a way to avoid this trap of heavy aerosol being thrown away with the clouds? In Fig. 4 and Table 1, we explore variations of the average AOT and the average Å with variations of the cloud screening thresholds. The results are plotted as a function of the estimate of the cloud contamination. To estimate the cloud contamination we calculate the average cloud variability for all the measurements with positive $\delta\tau^{cloud}$ or $\Delta\tau^{cloud}$. The cloud variability is then converted into the cloud optical thickness using the relationship shown in Fig 4 bottom panel. Here the lidar measured variability of the cloud optical thickness is plotted as a function of the actual cloud optical thickness. This relationship basically suggests that the cloud optical thickness is on average twice the variability of the cloud optical thickness across 1 minute.

As expected, relaxation in the SVA threshold increases the average AOT and decreases Å, a clear evidence of the cloud contamination. However, correcting for the cloud contamination corrects for the change in Å, leaving it practically constant and still leaves in some cases a higher value of the AOT. Note that the minimum value of the AOT indicates an optimum selection of the cloud screening threshold with minimum contamination. The results of the process for 10 AERONET sites are summarized in Table 1. For some of the locations (Rome, Kanpur, Mongu) the SVA did not change significantly the average AOT but increased the data rate by 4-20%. For other sites SVA increased the average AOT by 0.02 or 9% for Alta Floresta up to 0.08 or 20% for Beijing. Relaxing the SVA threshold and correcting for the cloud contamination still did not make a significant difference for Rome, Kanpur & Mongu but increased the average AOT for other site with a maximum increase of 0.12 for Beijing. The large difference in Beijing between the L1.5 and the SAV algorithm can be traced back to Fig. 1. The heavy aged pollution in Beijing with AOT values as high as 3.0 are sub-sampled in the L15 algorithm better represented by the SAV algorithm.

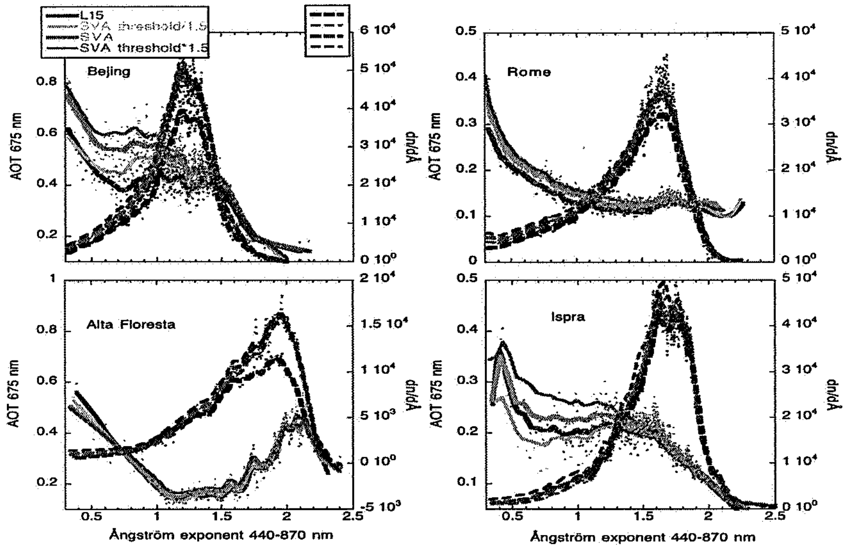

Fig. 3: Aerosol optical thickness (light color solid lines) and density of measurements (strong color dashed lines), dn/dÅ, as a function of the Ångström exponent, Å. The data, from 2001-2005, are sorted by Å and averaged in groups of 100.), dn/dÅ is the number of measurements, n, per unit Å. Black/gray – AERONET level 1.5 data; red/orange – spectral variability algorithm (SVA); green – SVA for thresholds reduced by 33%; blue/aqua – SVA with thresholds increased by 50%. The high AOTs with Å~1.0 in Beijing, China and Ispra, Italy (Melin and Zibordi, 2005) are due to accumulation of pollution over China and under the Alps respectively. Low Å values (~0.5) are due to desert dust. Alta Floresta, Brazil represent an area with concentrated biomass burning aerosol. Rome represents mostly local pollution with dust intrusions for lower values of Å.

Table 1: The average aerosol optical thickness (AOT), Ångström exponent (Å), and percent of measurements after cloud screening (%) with Å>0.3. Four estimate are made: **(1)** Average after SVA screening, **(2)** SVA corrected for residual cloud contamination, **(3)** no cloud screening except of Å>0.3, and **(4)** the AERONET L1.5 data. Comparison among the values of Å among the methods for a given site is used as a sanity check regarding residual cloud contamination.

Location	(1) SVA			(2) SVA corrected for cloud contamination			(3) No cloud screen (Å>0.3) corrected for cloud contamination			(4) AERONET Level 1.5 for Å>0.3		
	AOT	Å	%	AOT	Å	%	AOT	Å	%	AOT	Å	%
Rome 2001-05	0.140	1.40	70%	0.136	1.45	70%	0.144	1.49	81%	0.137	1.36	65%
Ispra 2001-5	0.189	1.58	67%	0.184	1.63	67%	0.212	1.68	85%	0.176	1.56	63%
Beijing 2001-05	0.493	1.13	72%	0.483	1.16	72%	0.535	1.17	86%	0.410	1.14	56%
Anmyon 1999-2005	0.300	1.15	65%	0.293	1.19	65%	0.317	1.25	80%	0.257	1.15	56%
Kanpur 2001-2004	0.421	1.05	74%	0.417	1.07	74%	0.420	1.07	80%	0.416	1.02	54%
Abracos Hill 2001-2005	0.259	1.60	59%	0.253	1.64	59%	0.264	1.66	76%	0.240	1.57	51%
Mongu 2001-2005	0.159	1.71	74%	0.156	1.75	74%	0.160	1.79	82%	0.152	1.68	70%
Alta Floresta 2001-05	0.279	1.67	69%	0.272	1.73	69%	0.299	1.78	88%	0.256	1.62	56%
Kashidoo 1993-2000	0.164	1.02	54%	0.158	1.07	54%	0.164	1.10	66%	0.184	0.92	50%
Mexico City 2001-05	0.249	1.61	71%	0.243	1.67	71%	0.263	1.73	90%	0.220	1.44	45%

Discussion

The SVA method and the inclusion of all the data practically with no further cloud screening of the AERONET level 1.0 data (for Å>0.3) in the analysis of long-term averages are based on existence of spectral difference between aerosol and clouds. Therefore we limited ourselves to Å>0.3 and were not able to include pure dust such as observed in Capo Verde with Å<0.3 in our analysis. In Fig. 5 we analyze the statistics of occurrence of Å>0.3. Except of Capo Verde, the restriction of Å>0.3 retains 88-98% of the data. In Kanpur the restriction of Å>0.3 will exclude most of the dust in the spring time. Correction of the cloud contamination is based on a factor of 2 found to relate the cloud optical thickness and the variability of the cloud optical thickness across the 1 minute of AERONET observations. This was measured by lidar on stratocumuli in 3 different locations (maritime, rural, and semi-urban) and altitudes, 600, 2500 and 1000 m, respectively. This relationship should be established in more numerous cloud conditions. However, the fact that the corrected average value of Å are practically independent of the threshold of cloud screening indicates that the correction is performing well.

Summary

The correlation among aerosol, the humidity field and clouds introduces errors into aerosol climatology derived using rigorous stringent cloud screening. Using AERONET data we show that screening algorithm that uses spectral variability is able to discriminate better between clouds and aerosol, but probably the best climatology can be achieved using a relaxed cloud screening and estimating statistically the cloud contamination, subtracting it later from the climatology. We showed that using this technique we derive higher aerosol average AOT in some locations while keeping the same values in others. Much larger fraction of the data are used in the process, while still maintaining fairly constant Ångström exponent. Similar techniques may be also applied to satellite data of aerosol, e.g. MODIS (Remer et al 2005).

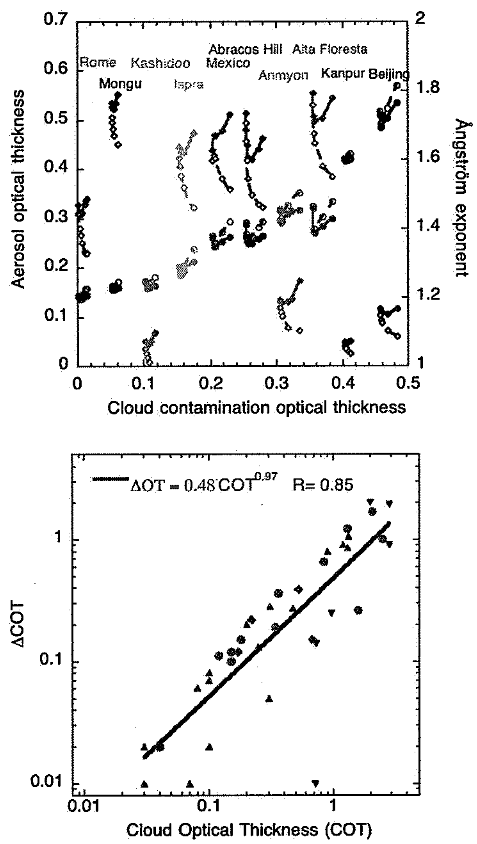

Fig. 4: Top - Aerosol optical thickness (circles) and Ångström exponent (diamonds) calculated for a range of SVA cloud screening thresholds and plotted as a function of the average residual cloud contamination. Full symbols – corrected for clouds. Open symbols – no correction for clouds. Bottom - Lidar measurements of the 1 minute variability in the cloud optical thickness (ΔCOT) as a function of the actual COT (for ΔCOT<1). Different symbols are for 4 different days and locations of measurements. The power law fit is for all the data.

Acknowledgment

We thank Tom Eck for comments on the paper. We thank the Aeronet project for the easy availability and use of the data world wide. We thank the following site principle investigators for effort in establishing and maintaining sites: Abracos Hill, Alta Floresta, Anmyon, Kashidoo, Mongu, Mexico city – Brent Holben; Beijing - Hong-Bin Chen & Philippe Goloub; Ispra - Giuseppe Zibordi.

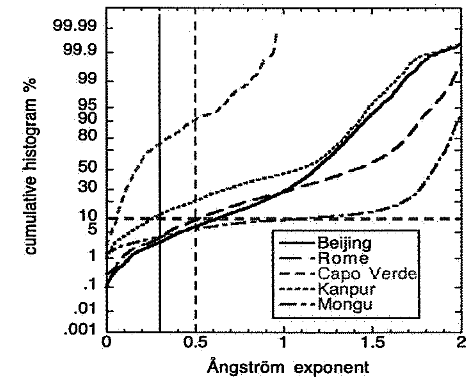

Fig. 5: Bottom: Cumulative histograms of the data as a function of the Ångstrom exponent for several locations. The cut off of Å=0.3 except of Capo Verde retains 88-98% of the data.

References

Chin, M *et al.*, Tropospheric aerosol optical thickness from the GOCART model and comparisons with satellite and Sun photometer measurements, *J. Atmos. Sci.,* 59, 461-483, 2002.

Chou, M.-D., Chan, P. K. & Wang, M. H. (2002) *J. Atmos. Sci.* 59, 748–757.

Holben, B.N., T.F. Eck, I. Slutsker, et al., 1998: AERONET—A federated instrument network and data archive for aerosol characterization. *Rem. Sens. Environ.*, 66, 1-16.

Holben B.N., Tanre D., Smirnov A., et al., An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET, *J. Geophys. Res,* 106, 12067-12097, 2001

Kaufman Y.J., L. A. Remer, D. Tanré, et al., A critical examination of the residual cloud contamination and diurnal sampling effects on MODIS estimates of aerosol over ocean, accepted to IEEE TGRS, 2005a

Kaufman, Y. J., I. Koren, L. A. Remer, D. Rosenfeld and Y. Rudich, The effect of smoke, dust, and pollution aerosol on shallow cloud development over the Atlantic Ocean, Proc. Nat. Acad. Scie., 102, 11207-11212, 2005b

Koren, I. Y. J. Kaufman, L. A. Remer, D. Rosenfeld and Y. Rudich Aerosol impact on the development and coverage of Convective clouds, Geoph. Res. Lett. 32 (14): Art. No. L14828 JUL 30 2005

Martins, J. V., D. Tanré, L.A. Remer, et al., MODIS Cloud screening for remote sensing of aerosol over oceans using spatial variability, Geophys. Res. Lett., 29(12),10.1029/2001GL013252, 2002.

Melin F. and Zibordi G, Aerosol variability in the Po Valley analyzed from automated optical measurements Geophys. Res. Lett., 32 (3): Art. No. L03810. 2005

Menon, S., J. Hansen, L. Nazarenko, Y. Luo, 2002, Climate Effects of Black Carbon Aerosols in China and India, SCIENCE, 297, 2250-2253.

O'Neill, N. T., T. F. Eck, A. Smirnov, B. N. Holben, and S. Thulasiraman, Spectral discrimination of coarse and fine mode optical depth, J. Geophys. Res., 108(D17), 4559, doi:10.1029/2002JD002975, 2003.

Remer, L. A., Y. J. Kaufman, D. Tanré, et al., The MODIS aerosol algorithm, products and validation. J. Atmos. Sci.,62 (4),947-973, 2005.

Sekiguchi, M., Nakajima, T., Suzuki, et al., (2003) *J. Geophys. Res.* 108 (D22), 4699, DOI:10.1029 2002JD003359.

Smirnov A., B.N. Holben, T.F. Eck, et al., 2000: Cloud screening and quality control algorithms for the AERONET database, *Rem. Sens. Env.*, 73, 337-34

Aerosol climatology using a tunable spectral variability cloud screening of AERONET data

Submitted to GRL Dec 13 2005GL025478

Yoram J. Kaufman[1], Gian Paolo Gobbi[2], Ilan Koren[3]
1. NASA/Goddard Space Flight Center, 613.2, Greenbelt MD 20771 USA, (yoram.j.kaufman@nasa.gov)
2. Inst. Scienze dell'Atmosfera e del Clima, CNR, Via Fosso del Cavaliere, 100, 00133 Rome – Italy
3. Dep. of Environ. Sciences Weizmann Institute, Rehovot 76100, Israel

Abstract

Can cloud screening of an aerosol data set, affect the aerosol optical thickness (AOT) climatology? Aerosols, humidity and clouds are correlated. Therefore, rigorous cloud screening can systematically bias towards less cloudy conditions, underestimating the average AOT. Here, using AERONET data we show that systematic rejection of variable atmospheric optical conditions can generate such bias in the average AOT. Therefore we recommend (1) to introduce more powerful spectral variability cloud screening and (2) to change the philosophy behind present aerosol climatologies: Instead of systematically rejecting all cloud contaminations, we suggest to intentionally allow the presence of cloud contamination, estimate the statistical impact of the contamination and correct for it. The analysis, applied to 10 AERONET stations with ~ 4 years of data, shows almost no change for Rome (Italy), but up to a change in AOT of 0.12 in Beijing (PRC). Similar technique may be explored for satellite analysis, e.g. MODIS.